Met.O.776
METEOROLOGICAL OFFICE

the meteorological magazine

OCTOBER 1966 No 1131 Vol 95
Her Majesty's Stationery Office

Recent
Meteorological Offiice
Publications

Scientific Papers

No. 21 Estimation of rainfall using radar—a critical review.
By T. W. Harrold, B.Sc., D.I.C. **6s. 6d.** (7s.)

No. 22 The solution of atmospheric diffusion equations by electrical methods.
By J. B. Tyldesley, B.A. **4s. 6d.** (4s. 11d.)

No. 23 Surface and 900 mb wind relationships.
By J. Findlater, T. N. S. Harrower, M.A., B.Sc., G. A. Howkins, M.B.E., B.Sc. and H. L. Wright, M.A. **5s. 6d.** (6s.)

No. 24 An atmospheric diffusion slide-rule.
By C. E. Wallington, M.Sc. **5s. 6d.** (5s. 11d.)

No. 25 The relation between Beaufort force wind speed and wave height.
By R. Frost, B.A. **3s. 6d.** (postage extra)

Prices in brackets include postage

METEOROLOGICAL OFFICE Met.O.776

THE METEOROLOGICAL MAGAZINE

Vol. 95, No. 1131, October 1966

551.5:06

WORLD METEOROLOGICAL ORGANIZATION FOURTH SESSION OF THE COMMISSION FOR SYNOPTIC METEOROLOGY

By C. J. M. AANENSEN

The Fourth Session of the Commission for Synoptic Meteorology (CSM) was held at Wiesbaden by invitation from the Government of the Federal Republic of Germany. The Session commenced on 7 March 1966 and lasted four weeks. There were over 130 representatives from 54 countries. The United Kingdom delegation consisted of Messrs V. R. Coles, L. H. Starr and C. J. M. Aanensen from the Meteorological Office and Instructor Captain J. R. Thorp, RN, from the Naval Weather Service.

All the meetings took place in the Kurhaus at Wiesbaden and, for the first time, simultaneous translations in five languages were available for the plenary meetings.

After welcoming speeches by the Director of the Deutscher Wetterdienst, by the Mayor of Wiesbaden, by a member of the Government of the Land of Hesse and by the Secretary General of the World Meteorological Organization, the work of the Conference got under way with Dr S. N. Sen of India as President and Dr K. T. Logvinov of U.S.S.R. as Vice-President. As is customary three committees were established, one to deal with codes, one for telecommunications and the third to deal with other matters. Some items of the agenda were dealt with to some extent by all three committees and in particular the impact of numerical data handling and World Weather Watch (WWW) was evident at many stages of the discussions.

There was a considerable exchange of views on the aspects of WWW, which are of direct concern to the Commission. The latter expressed its support in principle of the general lines of the planning effort described in a Secretariat document. Many delegates expressed the view that one of the major objectives of WWW should be to aim at a more uniform world-wide network of observations, that consequently special attention should be given to the ocean areas particularly of the southern hemisphere and that there was a need to improve the availability of southern-hemisphere data in the three World Meteorological Centres established for WWW. The Commission also expressed the view that increased attention should be given to the establishment of data archives at appropriate centres for the benefit of research workers. It was also noted that the output from Regional Meteorological Centres will vary, being dependent on the requirements of the associated National Centres. It was pointed out by some delegates that the

success or failure of WWW would be judged primarily on the service it renders to the small countries and to the emergent ones. It was realized that the planned output of the various centres will provide considerable assistance to those Services which are providing support for international aviation and maritime interests. Consideration was given to the present success in, and to the future possibilities of, obtaining observations (including upper air) from merchant ships and from commercial aircraft, but it was also realized that there were many areas of the world for which such observations could not be available.

There was considerable discussion on the engineering and organizational aspects of the global telecommunications system, and the Commission paid particular attention to the problems associated with the main trunk circuit which figures importantly in WWW planning. Various specialized studies relating to high-speed transmissions have been recently completed or will be in the near future. As part of its review of telecommunications the Commission examined the contents of the northern-hemisphere exchanges in respect of the type of data, selection of stations and frequency of transmission and also compiled a detailed list of stations whose reports should be included. Considerable emphasis was placed by the Commission on speeding up the collection of national reports, and on the use of approved telecommunication procedures and internationally agreed technical standards for transmission. Delegates also heard that plans were afoot to upgrade the New York–Offenbach cable to accommodate information in digital, non-digital and graphic form and at high speed (2400 baud), and that considerable improvements were planned for the circuit Moscow–Cairo. The Commission reviewed the exchange of southern-hemisphere data and the exchange of data between the northern and southern hemispheres and welcomed the planned improvements which were reported. Though the orders of priority of transmissions after restoration of a disrupted circuit were discussed for a long time it was not found possible to come to any agreement except that recent TEMP and TEMP SHIP part A reports should have first priority with recent hemisphere SYNOP and SHIP data. The Commission re-established its Working Group on Telecommunications.

The Commission discussed the dissemination and synoptic use of meteorological satellite data and expressed appreciation to the U.S.A. for their continuing efforts to advance the science of meteorology by means of satellites and for making current satellite products available to other Services. The Commission re-established the Working Group on the synoptic use of satellite data for the purpose of studying and preparing advice on the various related requirements. The increasing use of hydrological forecasting was recognized by the Commission who appointed a rapporteur to collect and prepare guidance material and liaise with the Commission for Hydrometeorology. The report of the Working Group on long-range weather forecasting was studied but no action was taken apart from appointing a rapporteur. Following consideration of the report of the Working Group on Methods of Analysis and Prognosis in the Tropics, the Commission agreed it could not make recommendations regarding methods for trial ; it appointed a rapporteur, instead of re-establishing the working group, and arranged for liaison on tropical matters with the Commission for Aerology (CAe). The re-establishment of the joint CAe/CSM Working Group on numerical weather prediction

was recommended with terms of reference to formulate requirements on codes, telecommunications, and presentation of output data.

Terms and definitions relating to visibility came under fire and it was recommended that certain terms should be dropped since they gave rise to misconceptions. On the question of the definition of mist and fog there was much discussion and despite some disagreement on the physical processes it was decided that the present conventional dividing line at 1000 metres is convenient and should be retained. A proposal by the Commission for Maritime Meteorology (CMM) to adopt a new table of equivalent wind speeds for the Beaufort Numbers was in effect referred back since new studies had become available since CMM-IV. Important advances in the physics of hydrometeors in recent years caused the Commission to recommend the establishment of a Working Group to deal with definitions and description relating to these items.

Following on the recommendations of the Working Group on Codes which had studied the minimum observational requirements according to the uses of the data for analysing and predicting small-scale phenomena of short duration, medium-scale and hemispherical-scale movements, the Commission reviewed the data requirements for all observations. For surface observations the Commission compiled a provisional list of requirements for further study. In particular there was a need for very considerable study of the requirements for observations of past and present weather and on this point the Commission considered that the findings of the Working Group were not a true minimum requirement but were admirable as a basis for further study. Agreement was reached as to minimum requirements for upper air observations. The main points of change which were recommended were that the dew-point depression should be reported in place of the dew-point and that provision should be made for reporting as standard levels data for 900 and 800 mb instead of 850 mb and for the addition of 600 mb data : data for 850 and 250 mb would not be required on a hemisphere basis. It was also agreed that the resolution of the reported wind should be changed from 10° to 5°. More specific criteria were developed for the determination of significant levels with respect to wind and maximum-wind levels. There was considerable discussion of the requirements in respect of non-meteorological data in messages and here computer requirements were often not acceptable to manual working. However, there was agreement on a proposed change in the identification of ship reports, the reporting of ship positions and in the identification format of TEMP and PILOT reports. Proceeding from these decisions the Commission then discussed code forms and made various recommendations, of which the following are of considerable interest. No changes were recommended for surface reporting codes except in the initial groups of the SHIP code and certain amendments in the subsidiary groups to allow better and simpler reporting of swell and sea temperature. New code forms were recommended for upper air reports. These codes are logical developments from the above-mentioned decisions as regards requirements and, in addition, make provision for an indication of the units used for the wind reports and incorporate a new way of indicating the sign of the temperature and the temperature to a resolution of 0·2 degC. It was recommended that these changes in code forms should all take place on 1 January 1968, but that changes of levels of upper air reports might have to be delayed

because they would produce an increased load on communications which is not acceptable until higher speeds are available on at least certain exchange routes.

As foreshadowed by the recommendations of the Working Group, the specialized aviation weather report code (AERO) was severely criticized and an entirely new code form was recommended. This code form includes only those elements which are required for aeronautical purposes and they are arranged in a self-evident form in the order of the corresponding plain language form. Certain indicator letters are introduced and provision is made for the reporting of weather by letter abbreviations as well as figures. Corresponding changes were also made to the forecast aviation codes. The present AERO code will however be retained for non-aviation uses. It was recommended that the Working Group on Codes be re-established under the more correct title 'Data Needs and Codes'.

On one afternoon, as a break from the continuous discussion, a symposium was held at which the following four lectures were given : 'Objective interpretation of forecast charts' by Dr O. Lönnqvist, Sweden, 'Numerical experiments leading to the design of an optimum global network' by D. M. Hanson, U.S.A., 'NMC numerical programme for the tropics' by F. W. Burnett, U.S.A., and 'Meteorological activities on board fishing protection vessels' by Dr H. Walden, Federal Republic of Germany.

Towards the end of the Session Dr S. N. Sen of India was re-elected as President of the Commission and Dr N. G. Leonov of U.S.S.R. was elected Vice-President.

The hospitality of our German hosts was much appreciated. In particular, the sight-seeing tour of the Taunus mountains and the valley of the Rhine, arranged by the Director of the Deutscher Wetterdienst will long be remembered by all delegates. The hospitality of the City Council of Wiesbaden and the Government of the Land of Hesse will also be pleasant memories.

551.576.11:551.576.12

STRATOCUMULUS — A REVIEW OF SOME PHYSICAL ASPECTS

By S. G. CORNFORD

Summary.—Present knowledge of the physical aspects of stratocumulus on which investigators have mainly concentrated is summarized and commented upon. Principally these aspects are the temperature and humidity structure, turbulence, liquid water-content, droplet size and concentration, radiation, shape of cloud top, turbulent exchange at the cloud top, cellular convection and effects of wind shear. Some problems which require further investigation are listed.

Introduction.—This article reviews the present state of knowledge of some of the physical aspects of non-precipitating stratocumulus cloud and the processes which govern its behaviour. The physical requirements for some types of altocumulus and stratus cloud are similar so that although attention is directed towards stratocumulus (Sc) much of the text will apply also to altocumulus (Ac) and stratus (St).

In temperate latitudes Sc is probably the most frequently reported type of low cloud. This is partly because in routine observations Sc is often the classification given to ill-defined forms which must nevertheless be classified.

Fortunately difficulties over the demarcation between cloud types will have had little effect on the findings reviewed here because most are based on clearly defined occurrences, usually associated with anticyclones.

Apart from the scientific desirability of understanding the formation, existence and dissipation of Sc there is a day-to-day need to use this understanding in forecasting practice. The formation and dissipation of Sc have large effects on the heat balance of the air near the ground and hence on surface visibility, fog, frost and even surface wind. There would be considerable economic benefit if the behaviour of a Sc sheet could be understood in a way that could be easily used in forecasting practice. No new forecasting techniques are suggested in this article which is rather an attempt to review the physical aspects of Sc which have already been examined and to indicate those which warrant further research.

Temperature.—Vertical profiles of temperature through Sc have been published by Schwerdtfeger,[1] Čurinova,[2] James[3] and Moore.[4] A notable and common feature is a marked inversion above the cloud top with temperature increases of up to 8 degC. Both James and Moore show occasions when an 8 degC change occurred through a layer only 100 m deep. In an analysis of 823 aircraft ascents over the Atlantic Ocean near 60°N 13°W Schwerdtfeger found 106 occasions of typical anticyclonic Sc. On nine of these the relationship of the cloud observations to the temperature profile was somewhat ambiguous and the observations were discarded, but on the other 97 there was invariably an inversion associated with the cloud top.

The temperature increase in the inversion layer appears to be related to the presence or absence of higher cloud above the Sc. On each of Schwerdtfeger's selected occasions there was no cloud above, or at the most 4/8 cirrus. James does not mention the presence or absence of upper cloud but his flights took place in anticyclonic conditions and so were probably free of thick upper cloud. (He certainly assumes that there was none when calculating the clouds' heat budget.) For nine of his eleven occasions Moore does not mention upper cloud : there was an inversion in each instance. On the other two Ac was reported above the Sc. With 3/8 – 4/8 Ac 2800 m above the Sc top he found a temperature change of 6 degC but with 7/8 Ac only 1500 m above the Sc there was no inversion. Čurinova too shows that when there is cloud above a Sc sheet, in the mean there is also a lapse and not an inversion of temperature above it. Her results are summarized in Table I. One surprising feature of this table is the zero lapse rate in the mean above a single sheet of Sc. This is quite opposite to the experience of the other workers,[1, 3, 4, 11] who found clearly defined inversions (although sometimes inversions had isothermal layers above them).

TABLE I—RELATION BETWEEN THE OCCURRENCE OF AN INVERSION ABOVE LAYER CLOUD AND THE ABSENCE OF CLOUD ABOVE IT

Cloud type	St	Sc	Sc	Sc	Sc
Height of top (km)	1·0	1·1	0·9	1·1	0·9
Number of layers above	0	0	1	2	3
Number of layers below	0	0	0	0	0
Mean lapse rate above cloud top (degC/km)	−3	0	3	4	1
Number of cases	33	21	24	11	6

Schwerdtfeger's soundings fell easily into two groups. Both showed a marked inversion but the first group showed a steep lapse rate above the

inversion whereas in the second the layer above the inversion was almost isothermal. Specific humidity continued to decrease in the isothermal layer. Schwerdtfeger concluded that in the second case the Sc had really formed beneath a boundary between air masses. No comment seems to have been made on Schwerdtfeger's work by other authors, nor is there any other evidence for two easily distinguishable types of temperature profile. It is possible that air-mass differences across the inversion arise because of the existence of the inversion. The limited movement of air through the inversion ensures that non-adiabatic effects which directly affect only air beneath the inversion, are little diluted by vertical mixing.

Hrgian[5] too found an inversion associated with the cloud top, but whereas in general the base of the inversion is found to coincide with the top of the cloud sheet, Hrgian found in 30 per cent of the occurrences of Sc–St near Moscow between 1951 and 1954 that the inversion extended down into the upper part of the cloud itself. He suggests that this is typical of old winter clouds and supports the suggestion with the argument that destabilization of the cloud by radiation from the cloud top and hence growth of the cloud up into the inversion is probably more active in winter than in summer. Presumably this is because there is more water vapour above the cloud in summer and perhaps because the nights in winter are longer. The observation that the cloudy inversion is found mainly in old clouds is interesting and may possibly explain why the feature has not been reported extensively and why it is not found near Moscow in the summer. Elsewhere the cloud may be less persistent than it is over the U.S.S.R. in winter.

Humidity.—Associated with the temperature inversion there is commonly a marked lapse of humidity above the cloud top.[1, 3, 4] The most extensive results are Schwerdtfeger's, obtained with meteorographs during the ascent on routine reconnaissance flights. They are shown in Table II. However,

TABLE II—FREQUENCY OF A GIVEN DECREASE IN RELATIVE HUMIDITY IN ASCENDING THROUGH THE INVERSION AT THE CLOUD TOP

R.H. decrease (per cent)	10	20	30	40	50	60	70	80
No. of cases (out of 95)	1	11	13	25	23	14	6	2

more accurate measurements were reported by James and Moore who used Dobson–Brewer frost-point hygrometers during level runs. They found that the average humidity above the cloud was about 20 per cent and that most of the sharp decrease in humidity occurred through a layer about 100 m thick.

Of the humidity inside cloud sheets there are no reliable measurements. Most show relative humidities less than 100 per cent. Such values are acceptable near the base and top of the cloud as averages of observations made both in and out of cloudy air, but it would be quite unexpected if they were the true values well inside a continuous sheet of Sc where the opacity is often very uniform.

There is also some doubt about the humidity below cloud. Sometimes the turbulent mechanisms maintaining a Sc sheet reach down to the ground and are influenced by the roughness of the surface, at other times the

turbulence is not associated with the ground and ceases some way above it. Schwerdtfeger's 97 ascents were on occasions when a dry-adiabatic lapse rate existed from the sea surface up to cloud base. He found that the humidity mixing ratio in two typical cases decreased from 4·5 and 4·9 g/kg at 10 to 40m above the sea surface to 4·2 and 4·6 g/kg respectively at the cloud base (corresponding to a dew-point decrease of about 1 degC) and concluded that convection from below did not play a decisive role in cloud production. However, as the relative humidity over the sea surface was about 70 per cent and as it is likely that water vapour was being exported through the top of the cloud, it seems more probable that this small humidity gradient persisted despite the 'convection' and played its part in the upward transfer of water vapour.

One might have expected James's and Moore's observations below cloud to be the more reliable since they are averages of several determinations made during level runs with what is regarded as a precise and well proven instrument. However, three out of James's four instances show humidity mixing ratios in the sub-cloud layer which were too low to give condensation at the level of the cloud base. Four of Moore's eleven observations show the same effect, despite lapse rates close to the dry adiabatic and humidity mixing ratios constant with height. Relative humidity was also measured as less than 100 per cent at cloud base and in cloud. The anomalies may be the result of an instrumental fault but certainly warrant examination.

Turbulence.—Turbulence of the air in Sc has been examined by a number of British and Russian workers. Čurinova,[2] Matveev and Kožarin[6] and Abramovič and Hrgian[7] use the Richardson number which they define as $\mathrm{Ri} = \tau/\sigma$, as an indicator of the intensity of turbulence. The thermal stability term $\tau = g\ (\Gamma - \gamma)/\overline{T}$ is obtained from aircraft soundings and $\sigma = (\partial u/\partial z)^2 + (\partial v/\partial z)^2$ is obtained from wind measurements by balloon. The term $(\Gamma - \gamma)$ denotes the difference between the adiabatic lapse rate and the observed lapse rate (Γ = DALR in clear air and SALR in cloud), g is the acceleration due to gravity, $\overline{T}$ is the mean absolute temperature of the layer, and $\partial u/\partial z$ and $\partial v/\partial z$ denote the vertical wind shears in two perpendicular directions. There is general agreement that Ri increases markedly above the cloud top with a corresponding decrease in the intensity of the turbulence. Results of these measurements are summarized in Table III.

TABLE III—TURBULENCE CHARACTERISTICS IN AND NEAR STRATOCUMULUS

Mean height base/top *metres*	Mean τ Below cloud s^{-2}	In cloud s^{-2}	Above cloud s^{-2}	Mean σ Below cloud s^{-2}	In cloud s^{-2}	Above cloud s^{-2}	Mean Ri Below cloud	In cloud	Above cloud
* 800/1100	1.6×10^{-4}	0.6×10^{-4}	3.4×10^{-4}	1.3×10^{-4}	1.0×10^{-4}	0.2×10^{-4}	1.2	0.6	14
† 1400/1800	—	—	—	—	—	—	14	1.4	62.7

* 21 occasions with no cloud above or below, after Čurinova
† 16 occasions after Matveev and Kožarin

As their indicators of the intensity of turbulence James,[3] Moore[4] and German[8] used the vertical accelerations which the turbulence induced in aircraft. Although, as pointed out by Scorer,[9] the fact that an aircraft being flown straight and level suffers vertical accelerations does not necessarily imply that it is in air that is turbulent in the sense that properties could be transferred by turbulent diffusion, nevertheless the erratic accelerograms

obtained do appear in most cases to have arisen from disordered air motions and hence turbulence. James interpreted his records qualitatively and found that up to about 60 m above the cloud top the turbulence was similar to that found in the cloud, but in the 100 m above that the turbulence decreased to almost zero. German evaluated a 'turbulent exchange coefficient' using a formula due to Dubov[10] and, as might be expected, found a similar decrease in turbulence above the cloud top. The vertical profile for one of his occasions is shown in Figure 1. From measurements in different cloud types German found the predictable result that Sc was moderately turbulent ; environments in order of increasing turbulence were : Ci, clear air at 2 km, Cs, St, Ns, Sc, As, jet-stream Cs, Ac, jet-stream Ci, Cu–Cb. There is no evidence in German's paper for or against James's hypothesis of an increase in the turbulence in Sc at night. Moore's results were similar to James's.

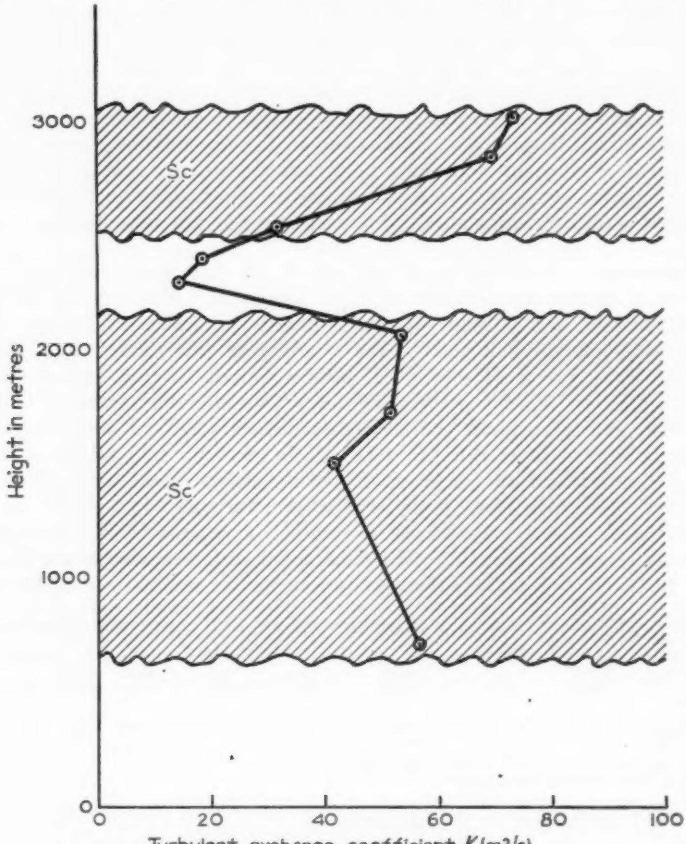


FIGURE 1—VERTICAL PROFILE OF THE TURBULENT EXCHANGE COEFFICIENT CALCULATED BY GERMAN[8] FROM AIRCRAFT ACCELEROGRAMS

(This coefficient, K, is not identical with the conventional meteorological coefficient of turbulent diffusion)

Liquid water-content.—The liquid water-content in Sc is of interest from the point of view of aircraft icing and the possible growth of precipitation. It could easily be calculated if the ascending air in fact behaved as one assumes it to do when deriving the saturated adiabats on a tephigram. At a level with air density ρ kg/m^3 and saturation humidity mixing ratio (SHMR) x g/kg the adiabatic liquid water-content, as it is called, would then be

$$W_a = \rho(x_o - x) \quad \text{g/m}^3$$

where x_o is the SHMR at cloud base. At Sc levels this means that the adiabatic water-content increases by about 1 g/m^3 for each km above the cloud base.

Measured values of the water-content in non-precipitating Sc, as summarized by Hrgian[5, 11] and Jones[12] for example are usually related to the adiabatic values. Water-contents are superadiabatic close to the cloud base, then gradually increase with height up to a maximum in the upper third of the cloud and decrease sharply to the zero value at the cloud top. The increase with height in the main part of the cloud gives a vertical gradient which is $\frac{1}{3}$ to $\frac{2}{3}$ of the adiabatic gradient, tending to the higher figure at low temperatures. The water-content profile for one particular occasion is shown in Figure 2. This profile is a typical one in the sense that, although the superadiabatic values near the base are missing and just below the level of maximum water-content the gradient approaches the adiabatic value, the overall appearance is typical and such departures from the mean profile are themselves typical.

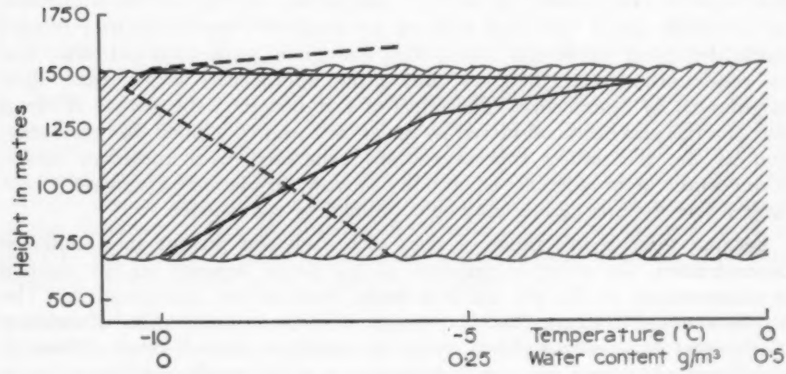


FIGURE 2—WATER-CONTENT AND TEMPERATURE PROFILES FOR ONE PARTICULAR STRATOCUMULUS SHEET, RIGA, 20 DECEMBER 1957 (after Hrgian[5])

——— liquid water-content ; — — — — air temperature

Because of the general relation between water-content and height above cloud base, many of the published tables giving frequencies of occurrences of different values of water-content must be used with caution : the values found depend partly on the distribution of Sc thicknesses in the area where

the measurements were made and may not apply in other areas. Another effect is that, because of the speed of the aircraft from which the measurements are made, locally high values are resolved only by fast responding instruments. This means that the frequency with which various values are found depends on the period over which the measurements were averaged and that comparisons ought only to be made within a coherent set of data. Such a set, taken from Hrgian[5] shows the expected result that the higher water-contents occurred at higher temperatures. At all temperatures 50 per cent or more of the values were 0·2 g/m^3 or less. Even in the temperature range in which high values were most often found (+5 to +10°C) 1·0g/m^3 was exceeded on only 3 per cent of occasions. In some American observations by Lewis[13] the median value was again 0·2 g/m^3. Lewis's observations were made in connection with aircraft icing studies and refer only to temperatures below 0°C. He used sampling times which were longer than those used in the Russian work and this may account for the comparative lack of large values. It would seem that the commonest values at temperatures below 0°C really are higher over the United States of America than over Russia. No comparable data are available for the United Kingdom.

Cloud droplet size and concentration.—Again the most comprehensive review is given by Hrgian[5] who discusses not only work in Russia but also in America and elsewhere. Droplets in cloud are found in a range of sizes. In Sc the largest sometimes reach the size of drizzle and even small rain drops (e.g. Singleton[14]). Mason[15] has suggested that they are drops which have had their effective fall path through the cloud much extended because of turbulence. While the bulk of the droplets grow for only short periods as they move in random eddying motion between the interior and the boundaries of the cloud, just because the motions are random a few drops may remain inside the cloud for several hours, long enough to grow to drizzle size, first by condensation and then, as they grow appreciably larger than their neighbours, by coalescence. The effect of turbulence on the growth of cloud particles has also been considered by Sedunov[16] who concluded that condensation in the fluctuating supersaturations associated with turbulent eddies is important in broadening an initially narrow droplet size spectrum to the stage where the broadening may be continued by coalescence.

Because there is this range of sizes with each size present in a different concentration, the effective diameter of the drops depends on the method of measurement or the use which is being made of the measurements. The simple average diameter $\Sigma nD/\Sigma n$, where n is the concentration of droplets of diameter D, gives weight to the large numbers of small drops. There is however doubt about the true concentrations of the smallest drops and considerable disagreement as to whether there are perhaps 10,000 droplets per cubic centimetre with diameters less than 2 μm or very few at all. Consequently determinations of the average diameter cannot be relied on. A common method of measuring the droplets in Sc is to measure the angular diameter of the corona around the sun, or more commonly, the moon (see for example Humphreys[17]). The diameter obtained in this way is a measure of the mean cross-sectional area of the droplets, and is about 10 μm. It is the effective diameter when we detect a cloud by eye just as the mean volume diameter $(\Sigma nD^3/\Sigma n)^{\frac{1}{3}}$ is when we detect a cloud by means of devices sensitive to the

mass of water they encounter. The mean volume diameter is used in work on aircraft icing, although more often it is the median value which is used. Typical values for Sc are between 10 and 20 μm. (Analogously, $(\Sigma nD^4/\Sigma n)^{\frac{1}{4}}$ is the significant diameter when considering rainfall rate — because the fall speed of a raindrop is approximately proportional to its diameter — and $(\Sigma nD^6/\Sigma n)^{\frac{1}{6}}$ is the significant diameter when 'seeing' by radar. Since in general droplet concentrations decrease as diameters increase the higher the index of D the more important the few large droplets become.) Considering diameters greater than 2–4 μm, typical concentrations of droplets in Sc range from one hundred to several hundred drops per cubic centimetre. On average, therefore drops are one to two millimetres apart.

Radiation effects.—Because of the longevity of Sc, radiation effects are important in its heat economy. Schwerdtfeger,[1] James,[3] Moore,[4] Hewson,[18] Gold,[19] Houghton and Brewer[20] and Feigel'son[21] have all discussed the heating and cooling rates of Sc because of radiation. Houghton and Brewer measured the long-wave radiation flux divergence through a Sc sheet as equivalent to a cooling rate of 0·4 degC/h. From calculations of the absorption of solar radiation and the loss of long-wave radiation in a typical cloud (and assuming a coefficient of turbulent diffusion in the cloud of 10 m²/s), Feigel'son found a daytime net cooling rate of 0·8 degC/h. James[3] considered that at night the absence of solar radiation and hence increased cooling at the cloud top increased the turbulence within the cloud and the layer of clear air next to the cloud top so that the mixing in of clear, warmer, drier air might cause the cloud to dissipate. In an earlier paper,[22] he found that daytime sheets of Sc with a dry layer above them tended to break at night whereas those with a less dry layer persisted. This may be because mixing with moister air is less of a dissipating influence but it is also consistent with a reduction of turbulence through the partial radiative blanketing effect of water vapour in the upper layer.[19, 21]

There is then general agreement that radiation plays a large part in the heat economy of an existing Sc sheet. There is less agreement over its role in cloud formation. Mal[23] suggested in 1931 that cloud could form at an inversion purely as a result of radiative flux divergence and this has been corroborated by Feigel'son's calculations and Staley's[24] recent measurements of the radiative cooling of initially clear humid air lying below a layer of dry air. No case study of an actual occurrence is known, however, and cloud *formation* by this process is not considered by most authors.

Shape of the cloud top.—The shape of the top surface of the cloud is a significant factor in the study of a Sc sheet because it indicates the depth of the layer in which exchange between the clear and cloudy air occurs.[3, 4, 22] The shape appears to be related to the radiative cooling of the cloud and the stability of the air in and above the cloud layer. Nepovitova[25] has found that for a given lapse rate in the cloud the top of Sc is much smoother beneath an inversion than it is when there is a cloud layer above the Sc. The statement must be worded in this way. The data as presented do not allow the simpler statement that the top is much smoother beneath an inversion than it is when there is no inversion above, nor can it yet be said that the top is smoother when there is no cloud above and vice versa, although the implication is that both these statements are likely to be true.

Turbulent exchange at the cloud top.—James,[3] Moore[4] and Turner and Yang[26] have proposed that an important mechanism for maintaining the cloud is the turbulent exchange between the cloud sheet and the clear air above it. James assumed that the heat needed to replace that lost by radiation came from diffusion, into the cloud, of warmer air from the turbulent lowest 100 m or so of the inversion and that water vapour lost by the cloud accumulated there. Moore came to the same conclusion. Like James he also concluded that the coefficient of turbulent diffusion must be of the order of $0 \cdot 3\ m^2/s$ by day and $1\ m^2/s$ by night. This mechanism implies a general ascent of the cloud top through the air. James found the height of the cloud top above the ground to be almost constant and supposed that this was achieved by a general subsidence of the whole air mass. Moore, however, found no need to invoke a general subsidence as he found the cloud tops did gradually extend upwards.

Turner and Yang emphasize the fact that the evaporation of a cloud into the dry air just above its top causes cooling and that this cooling may affect the rate at which the cloud top grows upwards. The evaporation which occurs when cloudy air is mixed with dry air to produce an unsaturated mixture results in the mixture being denser than either of its components. Turner and Yang carried out laboratory experiments with liquids (such as combinations of alcohol and water) which also produce mixtures denser than either of their components. Such mixing they call 'non-linear'. They arranged a lighter fluid resting over a denser one. They found that for a given level of turbulence in the lower fluid the rate of mixing of the two fluids was slower in the non-linear case than it was with ordinary 'linear' liquids and that a stable transition region formed above the interface between the non-linear liquids. They regard this stable transition region as being analogous to the inversion layer overlying a Sc sheet and they regard the top of the layer as the 'dynamical top' of the cloud. They find that the rate of advance of the dynamical top of the cloud into the undisturbed air above it can be expected to be slightly less than it would be if some of the air were not cloudy and no evaporation were taking place ; they do not assess the effect on Sc quantitatively but state that it may be negligible in practice.

There is a difficulty with Turner and Yang's model in that they require a cloudfree, moist and turbulent inversion layer, whereas in the layers examined by James and Moore the humidity fell off very rapidly in the bottom of the layer and the turbulence died well below the top of the layer.

Cellular convection.—Thin layers of Sc often show a cellular structure which invites comparison with convection as observed in the Bénard cell, where viscous forces oppose the buoyancy forces. The name F-cell describes a cell in which ascent occurs in the centre and descent at the edges and G-cell one in which fluid in the centre descends. F-cells form in fluids whose viscosity decreases with temperature and G-cells in those whose viscosity increases with temperature, such as gases. It seems contrary to experience that the cells in Sc should be G-cells, as this suggests, except possibly in the rare variety *lacunosus* which appears to have descending motion between tenuous filaments of extremely small water-content. Hrgian[11] refers to experiments in which F-cell convection occurred in air which had tobacco smoke mixed with it to increase its viscosity. By analogy, he suggests that

F-cells are usual in Sc because the water-content, and consequently the viscosity, increases with height, i.e. as the temperature decreases. No experimental work on the viscosity of cloudy air is known and theoretical considerations do not support this argument. For dilute suspensions of (rigid) spheres (of uniform size and small compared with the separation between them) in an incompressible medium Taylor and Glasstone[27] give the viscosity of the suspension as

$$\eta = \eta_0(1 + 5/2\varphi) \qquad \ldots \ldots (1)$$

where η_0 is the viscosity of the medium and φ is the fractional volume of the medium occupied by spheres. Equation 1 is often used practically for situations analogous to natural clouds. If it does apply to them then φ is of the order one millionth and we may conclude that the suspended water drops have a negligible effect on the viscosity and that the vertical gradient of water-content could play a decisive role in determining the sign of the viscosity gradient only in a closely isothermal layer when the viscosity gradient is itself very small. It must be concluded that the subject of the sense of the convection in cellular Sc still has many uncertainties and requires further study.

Other effects.—On a scale of several hundred miles Findlater[28] found that anticyclonic Sc tended to coincide with colder areas of air and clear skies with relatively warm areas. He was able to show that these cold and warm areas originated from successive pulses of cold and warm air which retained their identity after the fronts separating them had been omitted from the routine analysis. It is also likely, however, that initial air-mass temperature differences were accentuated as radiative cooling at the cloud top promoted convection and led to a cooling of the cloud and of the clear air beneath it which had no counterpart in the areas free of Sc.

A process which might lead to the formation of Sc or St has been discussed by Novožilov.[29] On some nights the wind profile develops a maximum in the lowest 1000 m — a so-called meso-jet — so that turbulence is likely to be greater above and below the wind maximum than at it where there is no shear. Novožilov found from balloon ascents that this sometimes led to the formation of a temperature inversion at the level of the maximum wind with lapse rates approaching the adiabatic above and below it. A case study of a meso-jet by Yutaka Izumi and M. L. Barad[30] showed the transfer upwards of a ground level inversion during the formation of the meso-jet and the establishment of less stable (but still isothermal) conditions from the ground up to 150 m. During the rise of the inversion its level corresponded with the progressively rising level of the wind maximum. Novožilov's data indicated that inversions rarely formed by this process alone. In 86 per cent of his cases an existing inversion was sharpened in association with the formation of a meso-jet.

A close following of the shape of the cloud top by corrugations in the inversion surface has been found by Zajcev and Ledohovič[31] (quoted by Hrgian[11]) in the Arctic. It was also noticed on a flight from Farnborough on 18 February 1965. In the clear air close to the cloud top the temperature fell by three to five degrees Celsius as the aircraft passed over cloud elements and rose again as it passed over the crevices between them. No such variations could be detected above the very smooth top found on 23 February.

Work on the degree of raggedness of the base of Sc by Zak and Marfenko[32] and by Perlat[33] has been summarized by Hrgian.[5] Fluctuations with an amplitude of 100 m or more have been measured with periods ranging from one to six hours down to fractions of a minute. Thus it seems that the reporting and forecasting of the heights of cloud bases with an accuracy smaller than 100 m is meaningless.

Detailed features within the main cloud sheet that have excited interest are rolls of cloud or thicker cloud along the wind[34] and across the wind. These have been discussed by Scorer[35] and result from convection within a shallow layer in the presence of strong and weak vertical wind shear, respectively. In otherwise continuous sheets of Sc, holes are commonly found downwind of hills. In many cases they are an extreme result of waves formed in the cloud sheet in the same manner as the more familiar lenticular cloud ; the typical temperature profile through a sheet of Sc with its inversion above a convective layer is just that which is so often associated with lee waves. An instance of rolls in Sc forming standing waves downwind of the Welsh mountains is given in reference 36.

Final remarks.—Stratocumulus is frequently a cloud form of great extent; horizontally it may be as broad as a small depression. The prime cause of cloud formation on this scale is usually thought of as the cooling by adiabatic expansion of ascending air, but such cooling can be of little importance in forming and maintaining Sc which is usually overlain by subsiding air and suffers only small pressure decreases as it moves along its trajectory. The cloud forms primarily as a result of non-adiabatic processes : heating from below alters the temperature profile to produce a cooling at what then becomes the cloud level, evaporation from the surface moistens the air aloft or water is injected into the layer beneath an inversion by the evaporation of spreading cumulus. On a smaller scale Sc may form both near to and well above the surface when wind shear provides the initiating turbulence while (because of the patchiness of the humidity and air temperature in the horizontal) the consequent differential advection leads to changes in the vertical profiles of humidity and temperature. It may also be that Sc on a smaller scale sometimes forms by radiative cooling of moist air.

Once formed the cloud is maintained as a result of the dynamic equilibrium between absorption of sunshine, loss of long-wave radiation, heating or cooling from below and mixing with warmer air from above the inversion. (The inversion itself is a subsidence inversion sharpened by erosion by the turbulent cloud and probably by radiative cooling of the cloud top.) The rate at which heat is redistributed by turbulence depends probably not only on wind shear but also on the intensity of convection brought about by radiative cooling of the cloud top. The pattern of turbulence is doubly important since, for the cloud to persist unchanged there must also be a dynamic balance between the transport of moisture into the cloud from below and its export through the inversion.

The practical application of our knowledge of Sc is mainly in forecasting its occurrence, persistence and dispersal. The only recent attempt at producing a forecasting rule has been James's work on nocturnal dissipation. It can be expected that some of the conflicting views and evidence presented in

this review will eventually be resolved. The resulting improved insight into the mechanisms of Sc will lead to better forecasts of its behaviour.

Some of the problems which seem to justify further work immediately are, not necessarily in order of importance :–

- (i) What are the quantitative effects of radiative heating and cooling on the cloud and the clear air beneath it ?
- (ii) What is the flux of heat and moisture through the inversion at the cloud top ?
- (iii) Does turbulence increase in the cloud over the sea at night ?
- (iv) How and why does the cloud thickness vary over the sea by day and night ?
- (v) How far are changes observed over the sea applicable over the land where they are complicated by topography ?
- (vi) Does cloud sometimes reach up into the inversion and if so is the cloud's behaviour affected ? Is it mainly older cloud which extends up into the inversion ? Do radio-soundings sometimes indicate saturated or moist air in the inversion when horizontal runs by aircraft show that the inversion does not extend down into the cloud ?
- (vii) Does Sc sometimes form primarily from radiative cooling of moist air below a dry layer ?
- (viii) Are Moore's and James's values of humidity below cloud too low ?
- (ix) Does the presence of higher cloud affect the validity of James's rule[22] ?
- (x) To what extent does wind shear lead to small scale Sc formation and dissipation ?
- (xi) What factors govern firstly the formation of extensive Sc by the spreading out of Cu and secondly its persistence or dispersal ?

Ultimately what are required are measurements of the various quantities in the heat and moisture budgets of the cloud system, an assessment of how and why individual quantities change with time and the effect of the changes on the behaviour of the cloud as a whole.

REFERENCES

1. SCHWERDTFEGER, W. ; Stratocumulus-inversionen. *Met. Rdsch., Berlin*, **1**, 1947, p. 150.
2. ČURINOVA, M. P. ; Some characteristics of turbulence on days with layer cloud. *Trudy glav. geofiz. Obs., Leningrad*, Vyp. 54, 1955, p. 31.
3. JAMES, D. G. ; Observations from aircraft of temperatures and humidities near stratocumulus clouds. *Q. Jl R. met. Soc., London*, **85**, 1959, p. 120.
4. MOORE, J. G. ; Some further observations from aircraft of temperatures and humidities near stratocumulus cloud. *Scient. Pap. met. Off., London*, No. 19, 1964.
5. BOROVIKOV, A. M. *et alii* ; Cloud physics. Jerusalem, Israel Program for Scientific Translations, 1963.
6. MATVEEV, L. T. and KOŽARIN, V. S. ; The role of turbulent mixing in the formation of the structure of stratus clouds. *Bull. Acad. Sci., Ser. Geophys., Moscow*, 1956, p. 1338.
7. ABRAMOVIC, K. G. and HRGIAN, A. H. ; Investigation of the conditions of development low stratiform cloud. *Trudy tsent. aerol. Obs., Moscow*, Vyp. 28, 1960, p. 3.
8. GERMAN, M. A. ; Turbulent exchange in clouds. *Met. Gidrol., Leningrad*, No. 10, 1963, p. 15. Translated as JPRS 22,048 — OTS 63 — 41238, U.S. Dept of Commerce, p. 31.
9. SCORER, R. S. ; Discussion of Reference No. 3. *Q. Jl R. met. Soc., London*, **86**, 1960, p. 114.
10. DUBOV, A. S. ; Determination of the coefficient of turbulence from the accelerations of aircraft. *Trudy glav. geofiz. Obs., Leningrad*, Vyp. 98, 1959, p. 54.
11. HRGIAN, A. H. ; Latest investigations on the physics of stratiform clouds. *Trudy tsent. aerol. Obs., Moscow*, Vyp. 47, 1963, p. 3.
12. JONES, R. F. ; Ice formation on aircraft. *Tech. Notes Wld met. Org., Geneva*, No. 39, 1961.

13. LEWIS, W.; Meteorological aspects of aircraft icing. Boston, Mass., American Meteorological Society. Compendium of Meteorology. Boston, Mass., 1951, p. 1197.
14. SINGLETON, F.; Aircraft observations of rain and drizzle from layer clouds. *Q. Jl R. met. Soc., London*, **86**, 1960, p. 195.
15. MASON, B. J.; Production of rain and drizzle by coalescence in stratiform clouds. *Q. Jl R. met. Soc., London*, **78**, 1952, p. 377.
16. SEDUNOV, JU. S.; Fine cloud structure and its role in the formation of the cloud particle spectrum. *Izv. Fiz. Atmos. Okeanol., Moscow*, **1**, 1965, p. 722.
17. HUMPHREYS, W. J.; Physics of the air, 3rd edn, New York and London, McGraw-Hill Book Co., 1940 (reprinted 1964 by Dover Publications, New York).
18. HEWSON, E. W.; The reflection, absorption and transmission of solar radiation by fog and cloud. *Q. Jl R. met. Soc., London*, **69**, 1943, p. 47.
19. GOLD, E.; Discussion of Reference No. 18. *Q. Jl R. met. Soc., London*, **69**, 1943, p. 228.
20. HOUGHTON, J. T. and BREWER, A. W.; Measurements of the flux of long wave radiation in the upper air 1953–54. *Met. Res. Pap., London*, No. 914, 1955. (Available in Meteorological Office Library, Bracknell.)
21. FEIGEL'SON, E. M.; Role of turbulency in process of radiation cooling of clouds. *Bull. Acad. Sci., Geophys., Moscow*, 1960, p. 197. English edition published in October 1960 by The American Geophysical Union of the National Academy of Sciences, National Research Council, Washington.
22. JAMES, D. G.; The nocturnal dissipation of stratocumulus cloud. *Met. Mag., London*, **82**, 1956, p. 202.
23. MAL, S.; Forms of stratified clouds. *Beitr. Phys. frei. Atmos., Leipzig*, **17**, 1930, p. 40.
24. STALEY, D. O.; Radiative cooling in the vicinity of inversions and the tropopause. *Q. Jl R. met. Soc., London*, **91**, 1965, p. 282.
25. NEPOVITOVA, A. F.; The shapes of the upper surfaces of cloud layers and their relation to the vertical gradient of temperature in clouds. *Trudy tsent. aerol. Obs., Moscow*, Vyp. 28, 1960, p. 49.
26. TURNER, J. S. and YANG, I. K.; Turbulent mixing at the top of stratocumulus clouds. *J. fluid Mechanics*, Part 2, *London and New York*, **17**, 1963, p. 161.
27. TAYLOR, H. S. and GLASSTONE, S.; Treatise on Physical Chemistry, 3rd edn, vol. 2. New York, Van Nostrand, 1951, p. 561.
28. FINDLATER, J.; Thermal structure in the lower layers of anticyclones. *Q. Jl R. met. Soc., London*, **87**, 1961, p. 513.
29. NOVOŽILOV, N. I.; A turbulent inversion — the result of activity of a mesojet. *Met. Gidrol., Leningrad*, 1963, No. 10, p. 33. Translated as JPRS 22,048 — OTS63 — 41238, U.S. Dept of Commerce, p. 41.
30. YUTAKA IZUMI and BARAD, M. L.; Wind and temperature variations during development of a low-level jet. *J. appl. Met., Lancaster, Pa*, **2**, 1963, p. 668.
31. ZAJCEV, V. A. and LEDOHOVIČ, A. A.; Temperature near the top of air mass fogs and stratus clouds. *Trudy arkt. antarkt. Nauk. Issled., Leningrad*, **1**, Tom 228, 1959.
32. ZAK, E. G. and MARFENKO, O. V.; Structure of the lower limit of cloud cover. *Trudy tsent. aerol. Obs., Moscow*, Vyp. 7, 1952, p. 3.
33. PERLAT, A.; Visibilité et hauteur de la base des nuages ; problèmes de mesures résolus ou à résoudre sur les aérodromes. Météorologie, Paris, 1954, No. 33, p. 9.
34. Notes and News — Stratocumulus cloud off Cape St. Vincent. *Met. Mag., London*, **83**, 1954, p. 219.
35. SCORER, R. S.; Natural aerodynamics. London, Pergamon Press, 1958.
36. DOWDING, J.; Stationary stratocummulus rolls. (Photograph). *Met. Mag. London*, **83**, 1954, between pp. 48–49.

551.515.42:551.515.82

MESO-SCALE INVESTIGATION OF A SQUALL-LINE

By R. R. McNAIR and J. A. BARTHRAM

Summary.—An analysis was made of a squall-line which moved over southern England on 3 July 1965. Isobars at ½mb intervals were drawn to demonstrate the development and movement of an isobaric escarpment, but barogram traces showed no severe or rapid fluctuations. Various isochrones were drawn to show the movement of the squall-line and its effects. The highest gusts were related to the maximum fall of temperature in accordance with rules for thunderstorm gusts. The surface temperature changes were compatible with the temperature changes to be expected because of a downdraught due to precipitation cooling. Squall-lines of the type described may occur when showers are slow moving and produce cooling in one area so that thermal gradients are accentuated.

To face page 304

PLATE I—SATELLITE TRACKING AERIAL AT THE ROYAL OBSERVATORY, HONG KONG

Signals from American weather satellites are intercepted by this aerial, stored on magnetic tape and fed into a converted television set. The displayed pictures are then photographed. The results obtained with this improvised apparatus are so encouraging that a more conventional system is being installed. (Official photograph supplied by Government Information Services, Hong Kong).

Photograph by R. K. Pilsbury

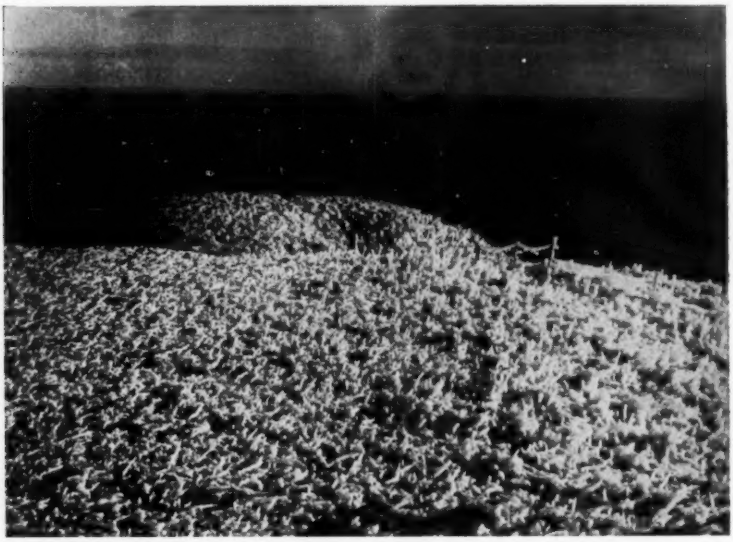
PLATE II—NOCTILUCENT CLOUD

(taken about 2215 GMT 27 June 1966 looking NW from Mumbles, Swansea)

Photograph by Miss Kay Pilsbury

PLATE III—NOCTILUCENT CLOUD

(taken about 2215 GMT 27 June 1966 looking WNW–NW from Bracknell, Berkshire)
This cloud is the same cloud as in Plate II and estimations show that it was over the Dublin area and at a height of about 86 km.



Photographs by J. C. Nicolson

PLATE IV—UNUSUAL 'ICICLE' FORMATIONS

These photographs were taken on 16 February 1966 looking east over the sea near Wick, Caithness. The cliffs are about 200 ft high and the ice formations were caused by water from a stream which normally flows over the edge of the cliff being blown back and freezing on the grass and twigs. The 'icicles' were up to 2 inches in diameter and a foot in length. The phenomenon lasted for about 10 days from the 7th and had never been seen before by local residents.

Introduction.—During the late afternoon of 3 July 1965 a squall-line developed over the south Midlands and moved southwards across southern England at about 20 kt, to merge eventually with the east-north-easterly flow over the English Channel.

General situation.—At 1200 GMT on 3 July 1965 pressure was high over and to the west of Ireland and relatively low over France and Germany. This gave a gradient for light northerly winds over England and Wales, with geostrophic wind values generally less than 10 kt. The air over England was rather cool for July ; the midday Aughton sounding gave a freezing level of 5500 ft, and was sufficiently unstable for scattered showers to be reported at this time north of about 53°N. Figure 1 shows the positions of the reporting stations mentioned in this article.

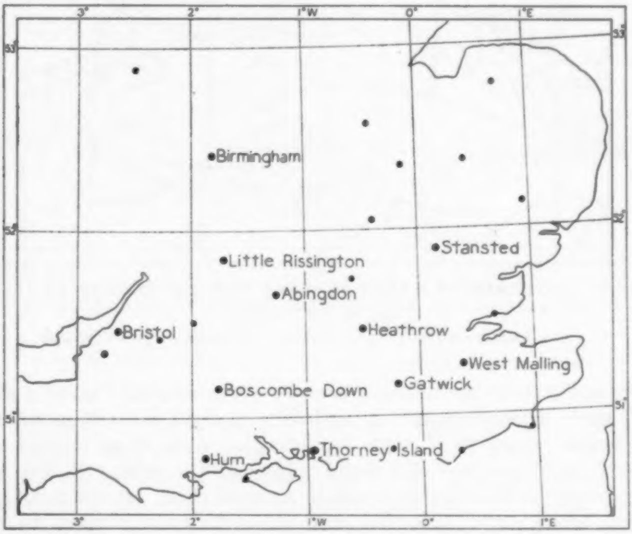


FIGURE 1—KEY MAP SHOWING NETWORK OF STATIONS USED IN INVESTIGATION
Stations referred to in the text are named

Development.—By 1500 GMT shallow heat lows had formed over southern England and the south coast sea breeze had penetrated inland to about 51°N. The surface isotherms showed a fairly even rise in temperature south-westwards from the Wash to the southern counties. These features are shown in Figure 2. Scattered light showers were occurring over the Midlands, notably in the Birmingham area, though being slow moving in the slack gradient they were reported as intermittent rain in some places.

The pattern was similar at 1600 GMT, with a continued tightening of the pressure gradient in a narrow band along 52°N. At the same time temperatures were beginning to fall in the Birmingham area as cooling by precipitation took effect.

Developments were occurring rapidly by 1700 GMT. The temperature had fallen in the hour by 3 to 5 degC in the Birmingham area and there was now a well-marked centre of cold air there. Further to the south the heat lows

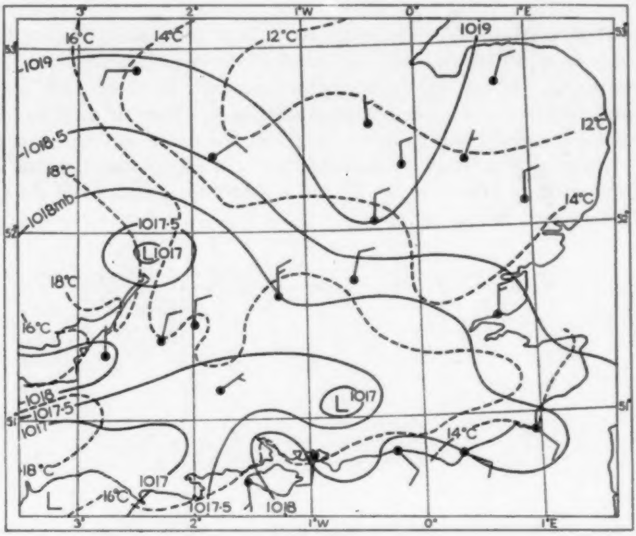


FIGURE 2—ISOTHERMS OF SCREEN TEMPERATURE AND ISOBARS AT 1500 GMT ON 3 JULY 1965

- - - Isotherms (°C); ——— Isobars at ½mb intervals

had deepened a little but temperatures were unchanged. Figure 3 shows the result of these developments ; a well-defined tight pressure gradient 'step' or 'escarpment' along 52°N, with a geostrophic wind of 50 kt, and with this a surface thermal gradient of 7 degC in 40 nautical miles. At this time rain or showers were extensively reported in an area some 100 miles long and 20 miles deep along 52°N, and this area was sufficiently marked to be given on a London/Heathrow Airport radar report at 1730 GMT.

However the surface winds continued to show a flow between north and north-east as far south as 51°N. Although an isobaric pattern of ridge/thermal low was providing the framework, the development was not related to any convergence of the sea breezes. The rainfall and associated cooling were being produced some 60 miles north of the penetration of the south-coast breeze.

Movement of the squall-line.—From 1700 GMT onwards the pattern moved south-south-westwards as an organized system at about 20 kt, and also extended eastwards. Abingdon noted a gust of 25 kt at 1753 GMT with a temperature fall of 4 degC during the next hour. By 1900 – 2000 GMT places from Bristol across the Salisbury Plain to London were affected. In the Larkhill/Boscombe Down area a light south to south-easterly sea breeze was displaced quickly by the fresh north-easterly winds between 1900 – 1930 GMT

and gusts up to 31 kt were recorded, with temperature changes of 4 – 5 degC. This temperature change occurred within 15 – 20 minutes of the arrival of the squall.

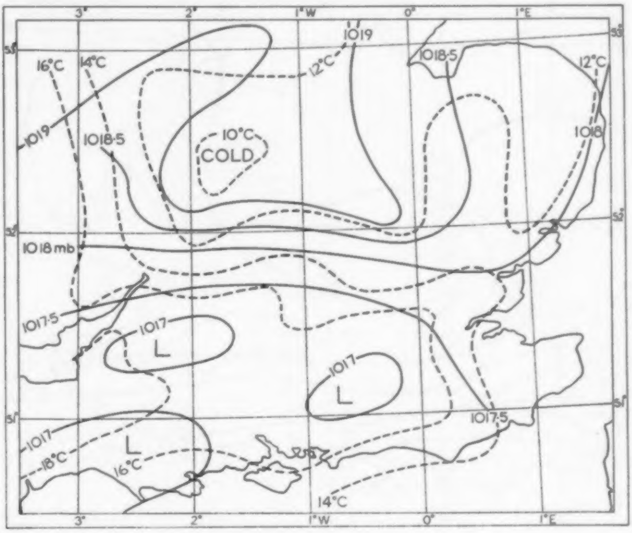


FIGURE 3—ISOTHERMS OF SCREEN TEMPERATURE AND ISOBARS AT 1700 GMT ON 3 JULY 1965

- - - Isotherms (°C); ——— Isobars at ½mb intervals

Over the eastern side of southern England the gusts were not so strong and mainly less than 20 kt, (examples are Stansted 17 kt at 1725 GMT and Gatwick 18 kt between 1950 – 2020 GMT), but strong synchronous gusts occurred along a line which moved southwards and was readily identifiable as far east as West Malling. However London/Heathrow Airport experienced a squally spell with gusts to 27 kt between 1840 – 1850 GMT. All observations for the area showed a fall in temperature of 3 – 4 degC within the hour following the stronger wind.

Figure 4 gives the position of the system at 2000 GMT, and is typical of the hourly chart analysis, showing how sharply marked the discontinuities appeared.

By 2100 GMT the shallow pressure lows over southern England had been displaced into the easterly flow over the English Channel, although the isobaric escarpment on the northern flank was still identifiable until 2200 GMT. Hurn, Calshot and Thorney Island were affected by gusts of 21 kt between 2050 – 2120 GMT, and had temperature falls of 2·5 – 3·5 degC.

The geostrophic-scale value of the pressure step was 45 – 50 kt during the period 1800 – 2200 GMT, and surface wind gusts up to 34 kt were recorded, with temperature falls of 4 – 5 degC in 30 minutes or less.

Rainfall and the associated temperature and wind changes.—Hourly charts were drawn delineating the areas where rain was occurring, irrespective of amount. Rain reported in the past hour was advected, and continuity was preserved across areas without observations to link with

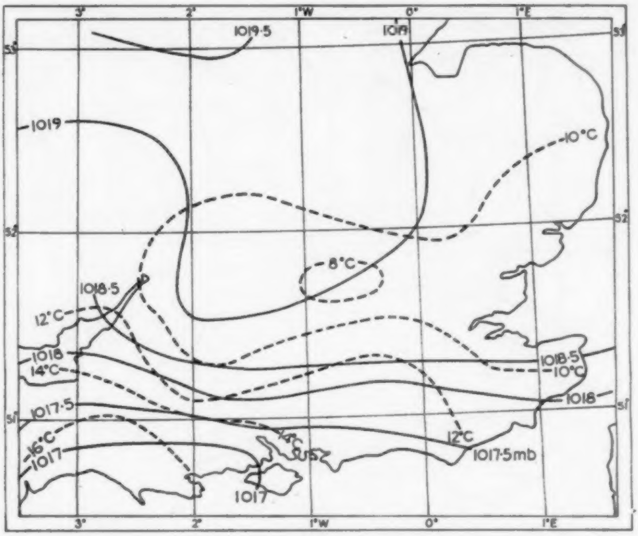


FIGURE 4—ISOTHERMS OF SCREEN TEMPERATURE AND ISOBARS AT 1500 GMT ON 3 JULY 1965

- - - Isotherms (C°); ——— Isobars at ½mb intervals

subsequent reports further south. Figure 5 shows the southward displacement at two-hourly intervals of the expanding area of precipitation which was associated with, or rather generating, the squall-line, and also the southward progression of the maximum reported hourly temperature falls. Figure 6 gives the isohyets of the rainfall during that period, and the isochrones of gustiness. An interesting feature shown by these two charts is that although the squall was most readily identified as moving south or south-south-westwards, the area of rain moved south-eastwards and expanded in an easterly direction. It appears that the gustiness was carried southwards by the north to north-easterly surface winds whilst the north-westerly 850 – 700 mb flow displaced the main rain area from the Midlands to give a maximum over Kent.

The pool of cold air produced by the rain moved south-eastwards too, and Figures 3 and 4 show that a closed isotherm of 10°C near Birmingham at 1700 GMT became a centre of 8°C near London at 2000 GMT. These temperature values seem to be in good agreement with an article by Wallington,[1] which states that the Celsius temperature of air reaching the ground in a downdraught due to precipitation cooling may be as low as, but not lower than, 1½ times the height of the 0°C isotherm in thousands of feet. On this day with a 0°C isotherm level of 5500 ft the expected temperature would be about 8°C.

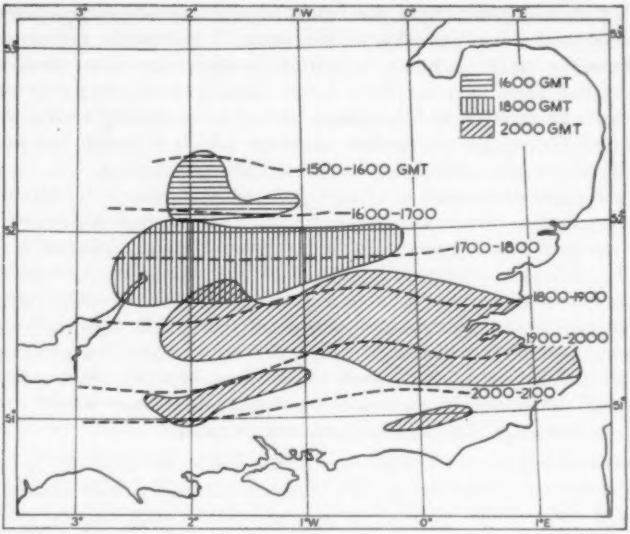


FIGURE 5—MAIN RAIN AREAS AT 1600, 1800 AND 2000 GMT ON 3 JULY 1965 AND LINES SHOWING THE PROGRESSION OF THE MAXIMUM REPORTED HOURLY FALLS OF TEMPERATURE DURING THE EVENING

(Fall > 3 degC except for 1500–1600 GMT when it is > 2 degC)

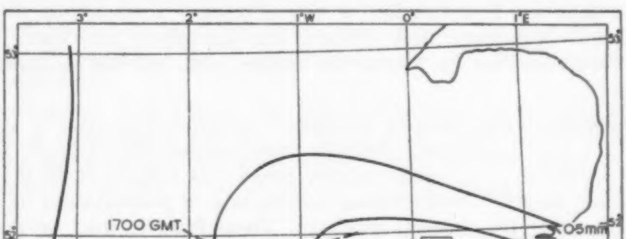


FIGURE 6—ISOCHRONES OF GUSTINESS AND ISOHYETS BETWEEN 1500 AND 2100 GMT ON 3 JULY 1965

- - - Isochrones of gustiness; —— Isohyets;
Boxes contain spot values of maximum gust in knots

Figure 5 demonstrates how the isochrones of maximum temperature fall advanced with the leading edge of the rain. A feature in the area west of 1°W, where the main gustiness occurred, is that only two places reported heavy rain and these only briefly — Little Rissington at 1832 GMT and Hurn at 2120 GMT. In general, in this area, a line of only very light rain or showers accompanied the squall. A further outbreak which followed the squall was also mainly slight and some places remained dry throughout.

A further point of interest is to apply the rules suggested by Fawbush and Miller[2] regarding gustiness in thunderstorms. They found a high correlation between the surface temperature change and the highest gust of a thunderstorm. If a fall of 4 – 5 degC is applied to their diagram then an expected maximum gustiness of 30 – 34 kt is found. This speed is very close indeed to the values recorded during the passage of the squall, although the depth of instability was in this case well below the requirement for thunderstorms. The upper air soundings indicated cloud tops between 6000 – 8000 ft at midday, and the midnight ascents showed that these tops would have risen to 8000 – 10,000 ft during the afternoon and evening.

Pressure changes.—A comparison of the 1200 GMT chart for 3 July 1965 with the 0000 GMT chart for 4 July shows remarkably little change in the pattern and value of the pressure field ; the disturbance had developed and disappeared with little or no trace. Even during the critical period 1500 – 2100 GMT there was only about 1·5 – 2·5mb variation at individual stations, and in the north and south of the affected area changes were 1 mb or less. Barograms showed no severe or extremely rapid fluctuations such as occur on occasions near instability squalls. Over the Salisbury Plain area they showed a slow fall from midday, a step of 0·5 mb at about the time of the squall (1900 – 1930 GMT), then a steady rise of 2 mb by 2100 GMT. A similar pattern is repeated on the barograms further east, but the sharpness of the step is lost.

Conclusions.—The essential features to produce this type of squall-line seem to be : (1) an air mass sufficiently moist and unstable to produce showers over the Midlands ; (2) winds initially sufficiently light to make the showers slow moving, thereby concentrating cooling due to precipitation to one area and accentuating the thermal gradient. These features may be present for example when heat lows develop over southern England in a light northerly airstream.

REFERENCES

1. WALLINGTON, C. E. ; Observations of the effects of precipitation downdraughts. *Weather, London*, **16**, 1961, p. 35.
2. FAWBUSH, E. J. and MILLER, R. C. ; A basis for forecasting peak wind gusts in non-frontal thunderstorms. *Bull. Amer. met. Soc., Lancaster, Pa.*, **35**, 1954, p. 14.

551.5:061.4:63

KENT FARMERS' FIELD DAY, EYNSFORD JUNE 1966

By J. COCHRANE

On 29 June a Field Day was arranged at Eynsford, Kent by the National Agricultural Advisory Service (NAAS) and the Agricultural Land Service of the Ministry of Agriculture, Fisheries and Food, in association with Wm Alexander (Eynsford) Ltd. The main purpose of the Field Day was to demonstrate the owners' approach to the problems involved in making the best possible use of the land and resources available to them.

The present complex of farms which covers about 1650 acres and extends for about 4 miles along the Darenth valley and varies in height from 100 to 560 feet above sea level, has grown steadily from the original 100-acre Home Farm which was bought in 1892.

The farming system was originally established around a dairy herd, and such a herd is still one of the six main enterprises. Activities now include breeding for beef and growing crops of barley, wheat, ryegrass, lucerne (own variety), beans and peas, apples, hops and the recent innovation of 'year-round' chrysanthemums under glass.

In this diversified type of farming the owners make extensive use of Meteorological Office facilities, subscribing to the 'fine-spell' service as well as maintaining frequent contact with the London Weather Centre. The County Agricultural Adviser felt that this close association between the owners and the Meteorological Office offered a good opportunity to bring home to a large section of the farming community the range of meteorological services and advice which can be offered to farmers.

At the Field Day a display under the title 'Meteorology and Agriculture' was arranged by the Meteorological Office. It consisted of wall cards detailing the services available to farmers by subscription, where to obtain forecasts by telephone, and examples of the type of problem which could be handled experimentally or by advice through local NAAS offices. Cards showing how the available meteorological services were used on this complex of farms during the year were prepared by NAAS and arranged around a ½-inch map of Kent which depicted the distribution of average annual rainfall and the location of rain-gauges in the county.

Instruments used in agricultural investigations were also displayed, among them a working thermograph and hygrograph and a surface-wetness recorder working under simulated intermittent rainfall, as well as a rain-gauge and sunshine recorder.

Of the thousand or so people who visited the farms rather more than half visited the meteorological exhibit. Many of them came just to look at the display but about a hundred asked definite questions and quite a number made comments on the work of the Office, the majority of them being favourable.

About a quarter of the inquiries concerned the 'fine-spell' service and quite a number of farmers came up to say that they used the service and found it very helpful and reliable. A telegram addressed to Wm Alexander giving the start of a 'Fine-Spell Bravo' from the morning of the 29th was on display and caused considerable comment.

The map of rainfall distribution caused a good deal of discussion as well as some inquiries as to the availability of copies of it as teaching aids. These inquiries, as well as an offer of new rainfall records on the Isle of Sheppey, were referred to the Climatological Branch of the Meteorological Office.

Several farmers made inquiries about the cost of instruments and were referred to the instrument makers. Answering inquiries kept two people fairly busy throughout the eight hours of the Field Day, and the amount of interest shown made one feel that the time spent in preparing the exhibit had not been wasted and that this type of exercise might well be repeated with reasonable expectations of benefit both to the Office and to the farming community.

551.509.313:551.509.33

NOTES AND NEWS

Address by Dr Joseph Smagorinsky

At Bracknell on 23 June 1966, members of the Meteorological Office staff were privileged to hear a lecture by Dr Joseph Smagorinsky, Director of the Geophysical Fluid Dynamics Research Laboratory of the United States Environmental Science Services Administration.

The research on the general circulation of the atmosphere carried out by Dr Smagorinsky and his colleagues has won wide acclaim. It constitutes the greatest advance in the science of meteorology of the last decade, and has opened up possibilities for many exciting developments. In the experiments, the atmosphere has been modelled numerically, and its behaviour with time studied by predicting the changes implied by basic physical laws. The calculations have required the largest electronic computers yet manufactured. In general, the objective is to supply as little information to the model as possible at the initial time so that it has to build up its detailed picture of what the atmosphere is like from the physical processes known to be acting. It is usual for instance to start with an atmosphere that is isothermal and at rest. Then as the sun's radiation is absorbed and cooling by loss of infra-red radiation occurs, thermal gradients and hence winds are created. The characteristic vertical structure of the atmosphere gradually evolves. Later, the conditions for baroclinic instability are realized and middle latitude depressions and anticyclones appear. Eventually a state of statistical equilibrium is achieved and at this stage the statistics of the motions can be compared with the statistics for the real atmosphere. Some of these general circulation experiments have been taken to upward of 300 simulated days.

On this occasion, Dr Smagorinsky chose to talk mainly about the use of his general circulation model for medium-range forecasting, that is starting from real initial data and forecasting for up to 4 days ahead. Any model which treats the general circulation of the atmosphere successfully should also do well as a forecasting tool, and since it is quite possible in long-term integrations to obtain the right statistical properties of the atmosphere for the wrong reasons, it is evidently desirable that forecasts produced by this model should be tested on occasions when very detailed comparisons of forecast and actual changes can be made.

The model carries information — that is winds, contour heights, water vapour content and so on — at nine levels. The highest is at about 9 mb (included mainly so that radiative transfers involving ozone can be calculated), and the lowest is at about 991 mb, a level which is within the friction layer. Information at each level is mapped on to a polar stereographic projection of the northern hemisphere and finite-difference analogues of the primitive equations are solved over the hemisphere on a mesh of points that usually numbered 5000 per level. This gives a horizontal grid spacing of about 270 km at 45°N. New fields of the variables were calculated at each 5 minutes of simulated time. Water vapour is carried as a variable so that condensation, evaporation and the resultant changes in heat content are properly allowed for. Rainfall amount can be deduced, both that due to large-scale motions and that due to convection. In the model used for medium-range forecasting, radiative transfer of heat, and the transfer of heat between the atmosphere and the underlying surface were at first suppressed (they are of course included

in the full general-circulation model). Thus the model had no sources of energy, but acted only on the energy initially present. On the other hand certain effects which have not yet been put into the general-circulation experiment were included. The differential effect of land and sea was allowed for by assuming a constant climatological temperature for the sea, while the temperature of the land was determined by the condition of radiative equilibrium. Also, the topography of the earth's surface was allowed to produce vertical motions at the lower boundary.

Forecasts for 4 days ahead were made with 3 sets of initial data, 0000 GMT on 22 January 1959, and 1200 GMT on 9 and 14 January 1964 though most of the results discussed referred to the latter two. Because of difficulties in obtaining data for the equatorial zone, the fields were extrapolated smoothly southwards from areas of adequate data coverage. For this and other reasons the initial conditions for the model were unrealistic in certain respects and it took almost a day for instance for realistic mean rainfall amounts to be achieved. The forecasts differ from those in routine operational use in that for a period after they start off their accuracy improves with time. A characteristic feature is that, although they do not improve much on the results obtained by more conventional numerical models (such as are now used for shorter-period forecasts, up to perhaps 24 hours ahead), their accuracy beyond 24 hours falls off much less quickly. There are good reasons for hoping therefore that they will go a long way towards solving the medium-range forecasting problem, though this objective cannot be achieved quickly since the computing time required is too long with present computers for the model to be used operationally.

By any standard the results of the forecasts shown by Dr Smagorinsky were extremely good, but the audience was particularly impressed by the rainfall forecasts, which more familiar numerical models are unable to make with any accuracy. Forecast 12-hour cumulative totals over the United States for each 12-hour period were compared with the rainfall totals measured at 3000 observation points averaged to give 166 areal mean values. The correlation coefficients between forecast and observed totals were 0·7 on the first day falling to about 0·3 on the fourth day ; while a simple rain or no-rain verification showed that the model was correct for about 90 per cent of the area of the United States on the first day and for about 70 per cent on the fourth day. Charts showing computed and observed values demonstrated convincingly that, even on the fourth day, the computations gave a lot of useful information.

Finally Dr Smagorinsky showed the results of an integration which had been completed only a week or two before the lecture. This integration treated the same initial data as before, but the effects of radiation and sensible heat transfer were now included. A comparison of the fourth-day surface pressure fields for the integrations showed that significant improvements had resulted from the inclusion of the additional terms. The depth of a depression in the Atlantic was much improved as was the handling of a depression over Asia that had developed since the beginning of the forecast period.

To obtain forecasts of such a quality over such a period of time represents a monumental achievement and confirmed for his audience the pre-eminence of Dr Smagorinsky's group in the application of numerical methods to the study of the atmosphere.

A. GILCHRIST

551.507.321.2

First round-the-world flight of southern-hemisphere weather balloon

At a joint meeting of the World Meteorological Organization (WMO) Advisory Committee and the Committee on Atmospheric Sciences of the International Council of Scientific Unions at the WMO Headquarters in Geneva, on 22 April 1966, Mr V. E. Lally (head of balloon research of the National Center for Atmospheric Research in the U.S.A.) reported the first results of the launching of experimental free-floating weather-observing balloons designed for flight at constant height levels in the atmosphere of the southern hemisphere. He described the first round-the-world flight of a southern-hemisphere balloon which completed its first circuit on 9 April 1966, 9 days and 23 hours after its launch on 30 March from Christchurch, New Zealand. The balloon flew at an altitude of about 15 kilometres and returned to the longitude of its launch at a distance of approximately 2000 kilometres towards the equator, thus demonstrating the equatorward drift of the parcel of air in which it was embedded.

This first round-the-world flight was the successful culmination of a five-year research and development effort to design a balloon and radio transmitter system capable of tracing airflow over all the world, for ultimate use in an improved global weather-observing system.

The balloon flight was performed through the joint efforts of the U.S. and New Zealand, with endorsement of WMO and co-operation from many countries of the southern hemisphere. The balloon development programme was supported by the Environmental Science Services Administration of the U.S. and the flights were launched in New Zealand under Mr Lally's direction. Flights of the new lightweight balloons commenced on 4 March 1966, and during March the joint U.S. – New Zealand group released 16 balloons. During coming months approximately 90 more such balloons will be flown. Each balloon carries a radio transmitter, powered by sunlight, that is capable of being received up to distances of over 5000 kilometres. From the radio signals the positions of the balloons can be ascertained and the values of their weather measurements derived. The radio signals are received by a network of amateur radio observers at 11 locations scattered throughout the southern hemisphere. Reports are then mailed to the NCAR headquarters in Boulder, Colorado, where the balloon trajectories are compiled.

The balloons and radios are of an extremely lightweight design and the balloons are of 'super-pressure' type, which allows them to float at a constant height in the atmosphere for indefinite periods — until finally they fail or develop leaks. Later balloons in the series are expected to make as many as six or seven full flights around the southern hemisphere. Not only will the flights test the feasibility of the new balloon techniques but they will also give valuable new data on the windflow of the southern hemisphere where weather networks are sparse. The experiment, if successful, will result in new weather observing methods later to be used in the World Weather Watch — a co-operative weather observing and research effort now being planned by WMO in co-operation with the International Council of Scientific Unions and the International Union of Geodesy and Geophysics.

Noctilucent cloud

The noctilucent cloud shown in Plates II and III, which are reproduced from photographs taken near Swansea and at Bracknell, was also seen from many other parts of the country. An article on noctilucent clouds by J. Paton was published in the June 1964 issue of the *Meteorological Magazine*.

HONORARY DEGREE

We have pleasure in announcing that the University of Nottingham conferred the degree of D.Sc.(*honoris causa*) on the Director-General, Dr B. J. Mason, at a ceremony held in Nottingham on 3 September 1966.

METEOROLOGICAL OFFICE NEWS

Retirement of Mr G. A. Bull

The Director-General records his appreciation of the services of Mr G. A. Bull, B.Sc., who retired from the Meteorological Office on 21 July 1966. Mr Bull was a Sherbrooke Scholar of East London College, University of London, where he graduated with First Class Honours in Mathematics in 1925. He joined the Office in March 1926 as a Junior Professional Assistant at Cranwell. Subsequent postings included Felixstowe, Weston Zoyland, Renfrew, Malta and several Headquarters Branches, and during the war he was attached for a time to Headquarters, Balloon Command.

After the war Mr Bull's long association with library work began. At Harrow, and later at Bracknell, he was for many years responsible for the National Meteorological Library, the Editing Section and the Cartographic Drawing Office. His wide knowledge of the literature of meteorology made him a valued source of information on the various branches of the subject. For a long time he was Editor of the Meteorological Magazine and earned the gratitude of many contributors for the help he gave them. In the international field he served from 1953 to 1959 as the United Kingdom member of the World Meteorological Organization Technical Commission on Bibliography and Publications, and he was for some time the Vice-President of the Commission.

Mr Bull took a major part in the planning of the Library at Bracknell, and another of his tasks was the setting up of the Meteorological Office Archives. This was consequent upon the Public Records Act of 1958 and involved a completely new system for the preservation and disposal of departmental records.

A man of varied interests, Mr Bull includes among his achievements a proficiency in several languages, including German and Russian, and this was put to good use in the translation of papers coming to the Library. He encouraged the formation of a translating section in the Library, and his personal supervision contributed a great deal to its success.

The last phase in Mr Bull's career as an established civil servant began when he took up an Assistant Directorship in 1960, first in charge of Support Services and later in the rapidly developing field of Data Processing. In these posts he was increasingly involved in automation in the Office. It was at his suggestion that the name COMET was given to the present computer.

On retirement from established service at the end of March 1965, Mr Bull became a Senior Scientific Officer in the Forecasting Techniques Branch, where he produced two memoranda on procedures used in the preparation of numerical forecasts by the Meteorological Office.

He gave valued service to the Royal Meteorological Society and undertook the Honorary Librarianship from 1960 to 1964. His library interests also led him to become a Member of the Institute of Information Scientists.

In June of this year Mr Bull was offered the post of Administrative Secretary in the Library of the University of Reading and he took up this appointment on 1 September 1966. George Bull will be remembered as a good companion and a splendid colleague of equable temperament. We wish him well in his new venture, one for which he is so admirably fitted by qualifications and experience. C.W.G.D.

REVIEWS

A history of the theories of rain and other forms of precipitation by W. E. Knowles Middleton. 9 in × 5¾ in, pp. viii + 223, Oldbourne Book Co. Ltd, 1–5 Portpool Lane, London, EC1, 1965. Price 45*s*.

Dr Middleton comments in the preface to this book that he believes the history of meteorology has had less attention than that of any other scientific discipline of comparable scope. He has now done much towards the filling of this large gap in the history of science by writing his 'History of the Barometer', as well as the book now under review, and one which is now in course of production on the history of the thermometer ; in scientific journals he has written articles on the history of atmospheric optics and of the visibility problem.

This book covers the history of theories of all forms of precipitation, including dew, from the earliest writings in the Bible and by the classical Greek authors to about 1914. The first chapter brings us in 18 pages up to the beginning of the 17th century. From then to 1914 requires 198 pages. Besides the history of theories of precipitation there is much on theories of wind and on the relation of barometric variations to weather.

Volume I of Shaw's 'Manual of Meteorology' contains a roughly similar account of classical Greek views on wind, clouds, and precipitation but on more recent history is much less full than Dr Middleton's book.

Dr Middleton has read and absorbed a vast amount of literature which most of us would find strange and difficult. He expounds his knowledge in a clear, well-co-ordinated and witty fashion with many an apt quotation.

Many of the ideas which have been propounded through the centuries seem to us now quite fantastic. As examples can be quoted : wind as not air in motion but a 'dry exhalation' from the earth; squeezing of clouds by wind to produce rain; cloud droplets as hollow bubbles (called vesicles); air in motion as exerting less pressure than calm air; clouds as holding up the air above them to account for reduced pressure in cloudy weather in which otherwise the weight of water in the air would be expected to lead to higher pressure. As recently as 1849 such eminent physicists as Clausius and Bravais accepted the vesicle theory of cloud droplets.

In all the welter of strange ideas Dr Middleton is a clear guide careful to bring out the first glimmerings of the truth.

It is noteworthy that by no means all first discoverers of an important truth receive credit for it in modern literature. Until reading this book the reviewer had never heard of P. J. Coulier as the first to discover condensation nuclei or of P. H. Maille as the first to realize the importance of the latent heat of condensation in the cooling of rising saturated air.

A major lesson of the story is, as Dr Middleton emphasizes, that no real progress in explaining phenomena so complex as those involved in precipitation could be made until the relatively simple basic laws of thermodynamics and radiation had been established. A surprising number of physicists, now eminent for real progress in simpler fields, went seriously astray in meteorology.

G. A. BULL

Long-range hydrodynamic weather forecasting, edited by E. N. Blinova. $9\frac{3}{4}$ in × 7 in, pp. iv + 124, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London, EC1, 1965. Price : 27*s*.

This is a valuable collection of major Russian papers about dynamical long-range forecasting, admirably translated as part of the Israel Program for Scientific Translations. The increasing volume of Russian literature currently becoming available from this source represents excellent progress in the dissemination of research. In the absence of such a service many workers without access to adequate translation facilities must inevitably remain poorly informed of Russian work and suffer accordingly.

The present volume under the overall editorship of Blinova, herself an acknowledged authority in this field, contains seven papers by workers in the Department of Planetary Atmospheric Dynamics and of Hydrodynamic Weather Forecasting.

Blinova's own contribution describes a 10-level, divergent, vorticity equation model formulated with long-range forecasting in mind and incorporating a simplified treatment of radiative exchanges and other physical effects. She sets out in considerable detail a partially implicit numerical procedure for solution of the equations but no results are given in the paper. For extended forecasts clearly very powerful computing facilities would be required and these may not yet be available for the purpose.

Kurbatkin's model, originally proposed by Blinova, is of the vertically differenced vorticity equation type with two levels at 300 and 700 mb. He integrates the system over the northern hemisphere for up to 5 days by means of a Green's function technique using a 4-hour time step and a grid of 5 degrees latitude by 10 degrees longitude. Initial results show a spurious accumulation of zonal kinetic energy in middle latitudes believed to be a consequence of errors in the prediction of zonal velocity. These lead to excessive displacement of the pattern in middle latitudes and accordingly a convergence of westerly momentum there. A special form of smoothing of the non-linear terms was introduced as a means of stabilizing the zonal winds and this enabled forecasts to be taken to 5 days with a useful predictive value. Experimental forecasts have apparently been prepared using this method on an operational basis for the past few years.

Galin discusses the interesting question of predicting the zonally averaged properties of the circulation directly from the dynamical equations using covariance terms to represent the turbulent motions, predictive equations for the covariances also being developed from the dynamical equations. For some studies this is an attractive alternative to extended integrations giving the evolution in detail and it is known that there is interest in this approach elsewhere. Galin specializes the approach to a two-level model but unfortunately does not present results. Smirnov's related paper fills in the background by

giving some hemispheric distributions of covariances of 500 mb parameters. Current fields of these would of course be required as part of the initial data for any predictions on the lines of Galin's work.

Musaelyan discusses the way in which humidity prediction could be incorporated into dynamical forecasting schemes. His basic humidity forecasting equation is linearized making possible solutions in terms of associated Legendre polynomials.

Chekirda considers the well known analytic solutions of the linearized non-divergent vorticity equation which depend on the meridional profile of zonal wind having a particular form. He examines the effect of departures from this special form and shows, for example, how forecasts made by Blinova's 1943 method can be improved by correcting for the real zonal profile.

The final paper by Smirnov is concerned with long range forecasting of the zonal circulation. The paper contains examples of predictions of 70-day average circulations and these appear to have good predictive value.

The book provides a useful and up to date picture of the extent to which dynamical methods are being focused on long-range forecasting problems and clearly the effort in this direction in the U.S.S.R. is on a considerable scale.

G. A. CORBY

LETTERS TO THE EDITOR

Synoptic representation of moisture

An article by T. H. Kirk describing moisture representation using 'dew-point thicknesses' appeared in the July 1965 issue of the *Meteorological Magazine*. The same basic idea was employed in designing an overlay for computing precipitable water directly from plotted Canadian tephigrams.[1] It would be a simple matter to adapt the overlay to the British tephigram. Using a three-layer computation a rapid and accurate measurement of the 1000–500 mb precipitable water can be obtained from the plotted dew-point curve. In each layer an 'equal area' method analagous to the Väisälä technique is employed. Similarly the 'saturation precipitable water' can be obtained from the temperature curve. The mean relative humidity is the ratio of the precipitable water to the saturation precipitable water. The determination of all three quantities from a plotted radiosonde report can be carried out in less than a minute. The use of precipitable water as a moisture parameter has many advantages not the least of which is that it is a directly measured physical quantity while the 'dew-point thickness' is a more abstract moisture-related parameter. In addition all of the comments regarding the usefulness of 'dew-point thickness' apply equally well to the use of precipitable water.

The use of a 3-layer model in computing precipitable water values is advisable because on the average the precipitable moisture is concentrated in the lowest levels. Typically there is considerably more moisture in the 1000–850 mb layer than in the 700–500 mb layer, for example. The surface to 500 mb precipitable water might be considered a more meaningful quantity over mountainous terrain than the precipitable water in a particular isobaric layer.

The difficulty of forecasting moisture patterns is well known. It seems reasonable to expect, however, that the precipitable water field should be more conservative than the dew-point or dew-point depression patterns at a single

level. Success in forecasting moisture must depend on the accuracy, representativeness, and conservatism of the moisture parameter and the accuracy of the initial (observed) field. It is felt that the precipitable water patterns might be found particularly useful in short-range weather forecasting over restricted regions. It should be possible, for example, to determine accurate 'spot' values of precipitation rate from a combination of mean upward vertical motion, precipitable water and mean relative humidity based on a multiple-layer model. Such a procedure could be programmed for the computer to produce short-range quantitative precipitation forecasts.

315 *Bloor Street, West, Toronto, 5, Ontario.* H. L. FERGUSON

Comments on 'Precipitable Water' and 'Dew-point Thickness'

In any scheme for the quantitative forecasting of rain a knowledge of the vertical and horizontal distributions of moisture is required as well as a knowledge of the distribution of vertical motion. During the course of a semi-operational experiment conducted in the Forecasting Research Branch in 1963 into the rainfall forecasting problem, precipitable water charts, rather similar to those illustrating the article by Papež,[2] were constructed on a routine basis. The precipitable water in various layers and combinations of layers was examined in an attempt to determine the most useful for forecasting purposes and more particularly for use with the computed mean 1000–600 mb vertical motion fields which were available from the numerical forecasting experiment. The use of an overlay, as suggested by Ferguson,[1, 3] was contemplated but was not considered worth pursuing at that time: there were other difficulties which had to be overcome before it was considered possible to draw sufficiently detailed charts of any moisture parameter. One difficulty was the suspected inconsistency of performance between the humidity sensors used in different types of radiosonde. A greater difficulty of analysis arose because over the area to west and south-west of the British Isles the radiosonde network was inadequate for sampling the atmosphere in time and space as often as required. It was in an attempt to overcome this difficulty and to provide a more objective chart of moisture that certain proposals were made by Benwell.[4]

The 'dew-point thickness' charts proposed by Kirk[5] are to all intents and purposes the same as precipitable water charts, as Ferguson[3] remarks. Either 'precipitable water' or 'dew-point thickness' charts would be acceptable in a rainfall forecasting scheme if it were possible to construct these in sufficient detail, but since both parameters are computed from the same basic data, the difficulties mentioned above are not removed if 'dew-point thickness' is used instead of the normal 'precipitable water' parameter.

Meteorological Office, Bracknell G. R. R. BENWELL

REFERENCES

1. FERGUSON, L.; A tephigram overlay for computing precipitable water. Canada, Department of Transport, Meteorological Branch, Technical Circular Series CIR-3653. TEC-409, 1962.
2. PAPEŽ, A.; A remark on synoptic charting of moisture. *Met. Mag., London*, **95**, 1966, p. 210.
3. FERGUSON, L.; Synoptic representation of moisture. *Met. Mag., London*, **95**, 1966, p. 318
4. BENWELL, G. R. R.; The estimation and variability of precipitable water. *Met. Mag., London*, **94**, 1965, p. 319.
5. KIRK, T. H.; A useful synoptic representation of moisture. *Met. Mag., London*, **94**, 1965, p. 214.

THE METEOROLOGICAL MAGAZINE

VOL. 95 NO. 1131 OCTOBER 1966

CONTENTS

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, and marked "for Meteorological Magazine."

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

All inquiries relating to the insertion of advertisements in the Meteorological Magazine should be addressed to the Director of Publications, Her Majesty's Stationery Office, Atlantic House, Holborn Viaduct, London E.C.1. (Telephone: CITy 9876, extn. 6098).

The Government accepts no responsibility for any of the statements in the advertisements appearing in this publication, and the inclusion of any particular advertisement is no guarantee that the goods advertised therein have received official approval.

Printed in England by The Bourne Press, Bournemouth, Hants.

and published by

HER MAJESTY'S STATIONERY OFFICE

Three shillings monthly **Annual subscription £2 1s. including postage**

Dd. 125624 K16 10/66 S.O.Code No. 40-43-66-10